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RASP-04 Experiment Optical Data Report

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Accompanying CD (on the inside back cover) contains data files for this report.

14. ABSTRACT

The Naval Research Laboratory Ocean Optics Section (Code 7333) at the Stennis Space Center, Mississippi (NRL/SSC), participated in the RASP-04 field experiment in Mamala Bay, Hawaii, from 10 August to 5 September 2004. Physical and optical measurements (temperature, salinity, depth, absorption, and attenuation coefficients) were collected at seven stations, on each of fourteen sampling days. Following stringent calibration and processing procedures, reduced data were compiled and provided to Naval Air Warfare Center (NAWC) personnel in near real time, to facilitate analyses, interpretation, and mission planning. Following the experiment, more extensive quality control and data processing were completed back at NRL/SSC, and final results and plots are presented here (all data and plots are provided on an accompanying CD). The extremely clear-water environment of Hawaii presented challenges, as absorption values were close to instrument detection limits. Nevertheless, the data were carefully quality-checked and a high-quality data set was collected.

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RASP-04 EXPERIMENT OPTICAL DATA REPORT

Executive Summary

The Naval Research Laboratory Ocean Optics Section (Code 7333) at the Stennis Space Center, Mississippi (NRL/SSC) participated in the RASP-04 field experiment in Mamala Bay, Hawaii, from 10 August – 5 September, 2004. Physical and optical measurements (temperature, salinity, depth, absorption and attenuation coefficients) were collected at seven stations, on each of fourteen sampling days. Following stringent calibration and processing procedures, reduced data were compiled and provided to NAWC personnel in near-real time, to facilitate analyses, interpretation, and mission planning. Following the experiment, more extensive quality control and data processing were completed back at NRL/SSC, and final results and plots are presented here (all data and plots are provided on accompanying CD). The extremely clear-water environment of Hawaii presented challenges, as absorption values were close to instrument detection limits. Nevertheless, the data were carefully quality-checked and a high-quality data set was collected.

RASP-04 Experiment Data Collection

During the period of 10 August – 5 September, 2004, *in situ* physical and optical measurements were collected in the area of Mamala Bay in Honolulu, Hawaii. A profiling optical and CTD package, providing absorption (a) and attenuation (c) coefficients, temperature, salinity and depth measurements was deployed from the University of Hawaii's research vessel, Klaus Wyrtki. Coincident secchi disk measurements along with environmental observations were also made by NAVAIR personnel.

The seven stations denoted in Figure 1 were occupied on each of 14 sampling days during the period of the experiment; the stations are referred to in the ships log as stations B6-1 thru B6-7. The ac9 profiling package was deployed with a mechanical cable from R/V Klaus Wyrtki with the aid of the ship's hydraulic winch and crane. The package was powered with battery packs thus eliminating the need for an electrical cable while profiling. Raw binary data from the ac9 and CTD were logged internally with the ac9_plus and downloaded to a PC laptop after recovery of the package at each station.

The package was deployed at an average descent rate of approximately 0.4 meters per second. Initially, to determine the depth of the optical layer, the package was deployed to approximately 200 meters. The optical layer was found to occur at less than 100 meters, typically about 40 meters, hence it was determined that profiling to a maximum depth of 150 meters was adequate to characterize the inherent optical properties (IOPs) in the area of interest.

Optical Data Processing

Following collection of the *in situ* measurements, field calibrations of the ac9 were performed at the end of each day using nanopure water acquired from the

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University of Hawaii's water purification system. Each subsequent calibration was compared to the previous calibration to track the instrument stability and verify the validity of the calibration. If the calibration demonstrated any deviation, or drift, outside the accuracy of the instrument, with regard to the previous calibration, the calibration procedure was repeated to verify that the deviation was valid.

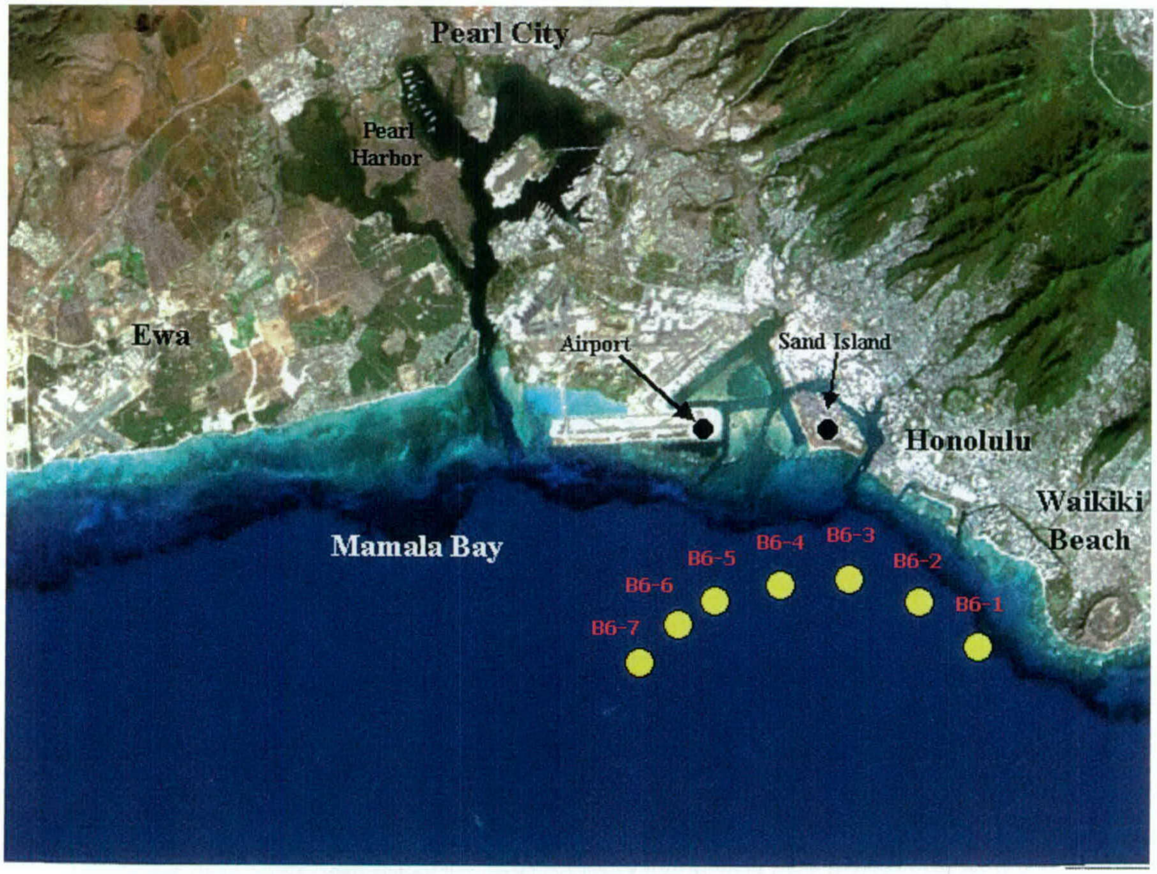

Figure 1. Station locations overlaid on Landsat image.

At each cast, all instrument data files were simultaneously merged and logged to the ac9_plus instrument. This ensured that all measurements were interpolated to the same depths, even though the individual sensors all sampled at different frequencies. Differences in sensor depths due to placement on the profiling package were also taken into account. Processing of the profile data started with extraction of the individual sensor hexadecimal meter files from the single binary file logged by the ac9_plus. Next, factory calibrations were applied to both the ac9 and CTD data files to produce raw ASCII data in engineering units. These individual meter files (ac9 and CTD), were then merged together into one file based on time, taking into account instrument lags and HAD (height above datum). With regards to instrument lag, both electronic and physical lag were accounted for. Electronic lag, in milliseconds, is associated with the amount of time it takes the instrument to complete a sampling cycle, i.e., the time it takes for the signal to be sensed at the detector, digitized, then stored in memory. These lag values are

generally provided by the manufacturer. Physical lag is associated with the amount of time required for the seawater to be exchanged in the sampling chambers of the ac9 and CTD. Physical lag, also in milliseconds, is calculated by the user based on pump flow rates, and plumbing and sample chamber volumes. Lastly, HAD in centimeters, takes into account the differences in mounting heights of the instruments on the profiling cage. The pressure cell on the CTD is designated as the datum or reference, and the distance, positive or negative, from this point to the mid point of any other instrument's sensing volume is measured and a depth offset is applied to the data. With the ac9 data now navigated with depth from the CTD and merged with the salinity and temperature records, further post-processing of the ac9 data could be accomplished.

Data post-processing for the ac9 absorption and attenuation measurements first involved corrections for instrument calibration errors. Ac9-measured values of nanopure water (field calibrations) were subtracted from the in-situ measurements. After analyzing all the ac9 calibrations that were made during the experiment, we determined that the best approach was to apply an average calibration to the entire data set. The second step in post-processing of the ac9 absorption data was to correct the data for temperature and salinity effects. The change in absorption due to temperature and salinity occur predominately in the red end of the visible light spectrum (i.e. ac9 channel at 715nm); this is also the spectral region used to scatter correct the data. Due to the clarity of the sea water in the area of interest, and the high variability of temperature and salinity in this water, the temperature and salinity corrections are critical in producing an accurate final product. Next, the absorption values were scatter corrected to account for the inherent overestimation of absorption due to uncollected scattered light in the absorption tube of the ac9 (an instrument design issue with the detector). Finally, pure water absorption values (these values are removed during calibration of the instrument) were added to the ac9 absorption and attenuation data, yielding total absorption and attenuation coefficients. Finally, the scattering coefficient ($b = c-a$) and the single scattering albedo ($\omega = b/c$) were calculated. Both these additional products are provided in the data files along with depth, salinity, temperature, absorption and attenuation coefficients.

Data Conventions

All data are provided on the accompanying data CD in simple ASCII row column text files with station information and data field identification in the header. Also, per special request from NAVAIR, data are provided in excel spreadsheet format. The time-series data are compiled into 7 excel spreadsheets, each containing data from a single station for the entire experiment, i.e., excel file 'PRF_10Aug-05Sep-04_B6-3_ac1c.xls' contains all ac9/CTD data for station B6-3 for the entire time period of the experiment (10Aug through 05 Sep 2004). In addition, 14 separate excel files are provided, each containing all station data collected on a single day, i.e., excel file PRF_24-Aug-04_B6-1-7_ac1c.xls contains all ac9/CTD data for all stations occupied on 24 August. All times noted in data headers and on plots are local time (Honolulu, HI). For a summary listing of all stations, including date, time, latitude, longitude, and ac9/CTD filenames, see excel spreadsheet NRL_ac9_Station_log.xls on the attached data CD or the hardcopy in the data binder.

File naming conventions for the time series data are as follows, using station B6-3 on 04 September 2004 as an example:

General prefix common to all files: i.e. PRF_4-Sep-04_B6-3

PRF = Profile Package
4-Sep-04 = Collection date
B6-3 = Station

Processed data, ASCII row column text file:
PRF_4-Sep-04_B6-3_ac1c.dat (processed ac9/CTD data file)

Post-script plot file names:
PRF_4-Sep-04_B6-3_AC9-1.ps (ac9 'a' and 'c' profile plot 1)
PRF_4-Sep-04_B6-3_AC9-2.ps (ac9 'a' and 'c' profile plot 2)
PRF_4-Sep-04_B6-3_AC9-3.ps (ac9 'a' and 'c' spectral plot)
PRF_4-Sep-04_B6-3_CTD.ps (Temperature and Salinity plot)

Excel Spread Sheets:
PRF_10Aug-05Sep-04_B6-3_ac1c.xls (All station B6-3 data for entire experiment, 10 August through 5 September 2004, and 'a' 412nm plot)

If postscript software is unavailable for viewing the *.ps plots on the data CD, Ghostscript freeware is provided for use on PC systems. See README.doc file in folder 'plot_viewing_software' on the CD for an explanation and http link to the software site. Note this software is free and available for installation on several platforms.

Results

Plots of temperature, salinity, absorption, and attenuation vs. depth for all station are provided in post-script format. These plots were modified at the request of Jack Gibbons to conform with RASP-04 file naming conventions, date formats, etc. For the absorption and attenuation profile data, two separate plots were generated for each station. The first plot includes the lower six ac9 channels (412, 440, 488, 510, 532, and 555 nm), while the second plot includes the upper three ac9 channels (650, 676, and 715 nm). Examples of the two types of plots are shown in Figures 2 and 3. The channels were separated into these two groups to help visualize the patterns in the data. The values of the last three ac9 channels (650, 676, and 715 nm), after the addition of pure water, were much larger than the first six channels, so the x axes of the two plots are scaled to help visualize the optical stratification. Surface-average spectral plots of ac9 absorption and attenuation coefficients and vertical profiles of temperature and salinity were also produced for each station (examples shown in Figures 4 and 5, respectively).

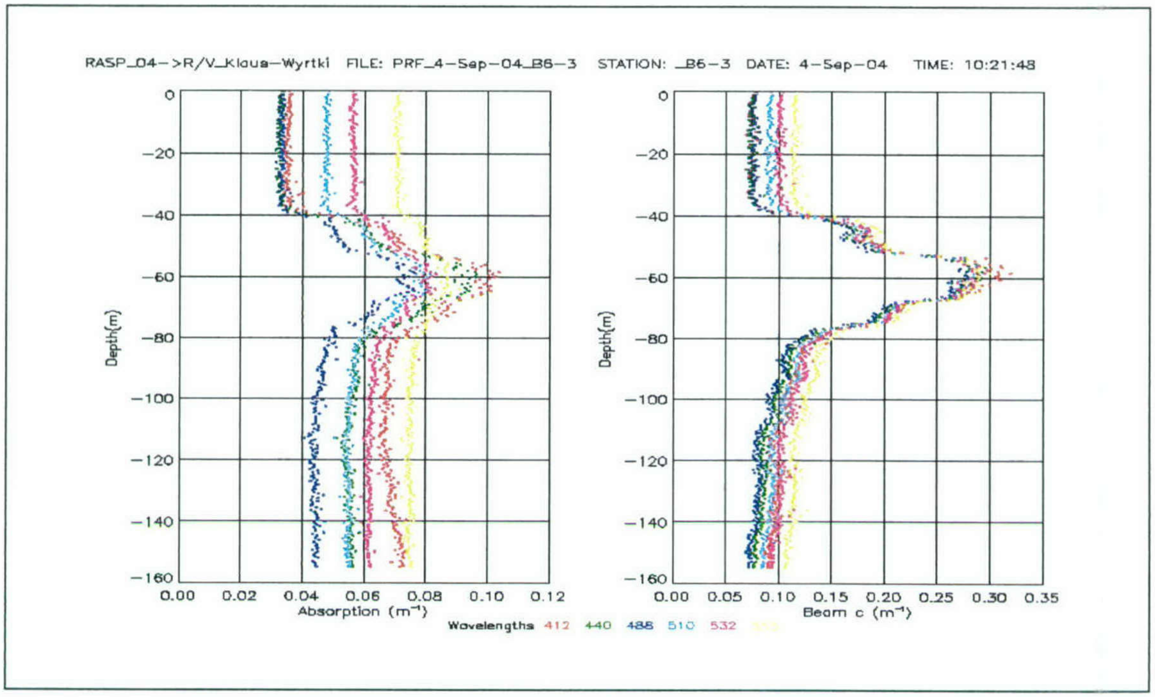

Figure 2. Example of ac9 absorption and attenuation coefficients vs. depth, shortest six wavelengths.

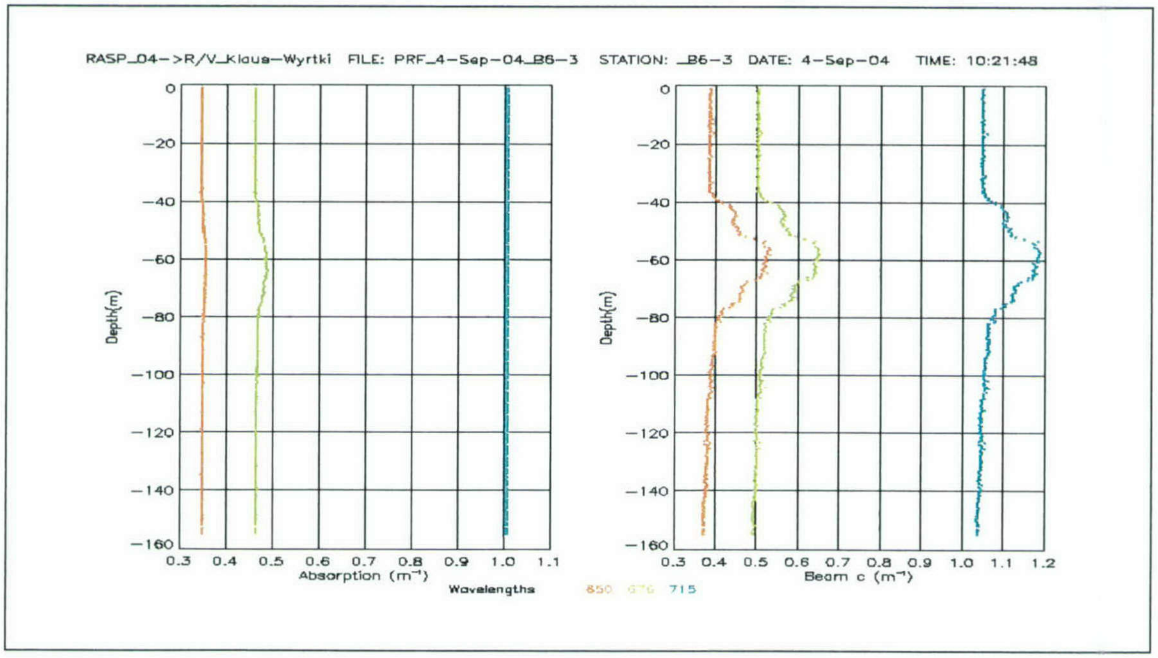

Figure 3. Example of ac9 absorption and attenuation coefficients vs. depth, highest three wavelengths.

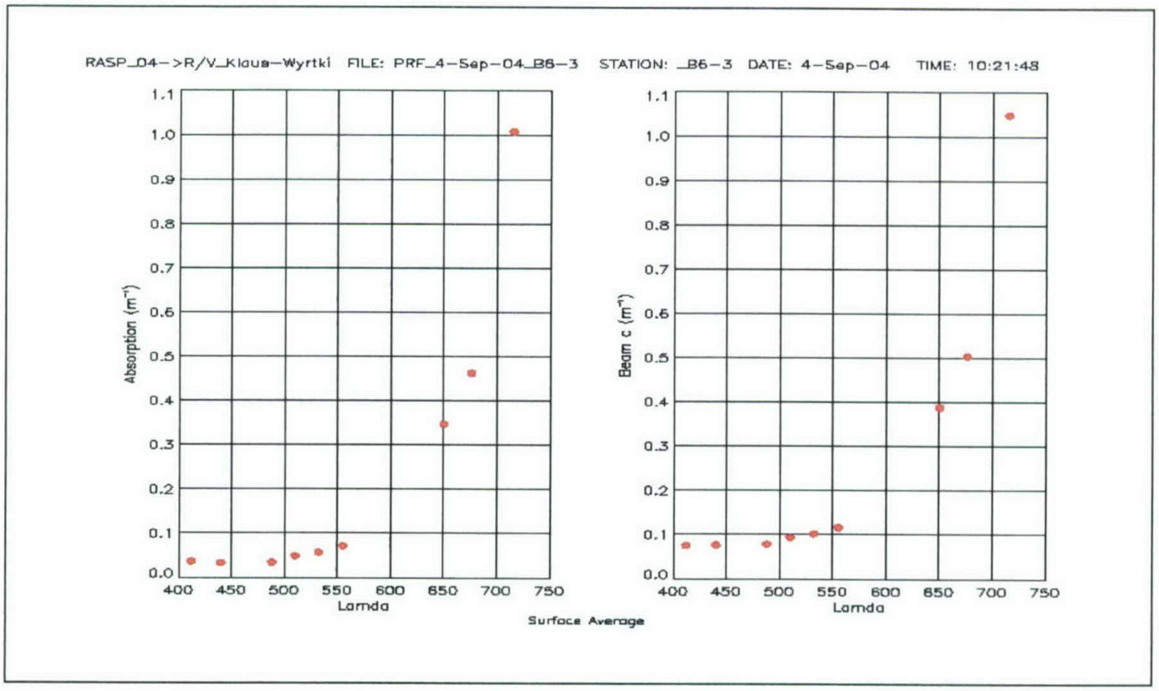

Figure 4. Example of ac9 absorption and attenuation coefficients vs. wavelength, surface averages.

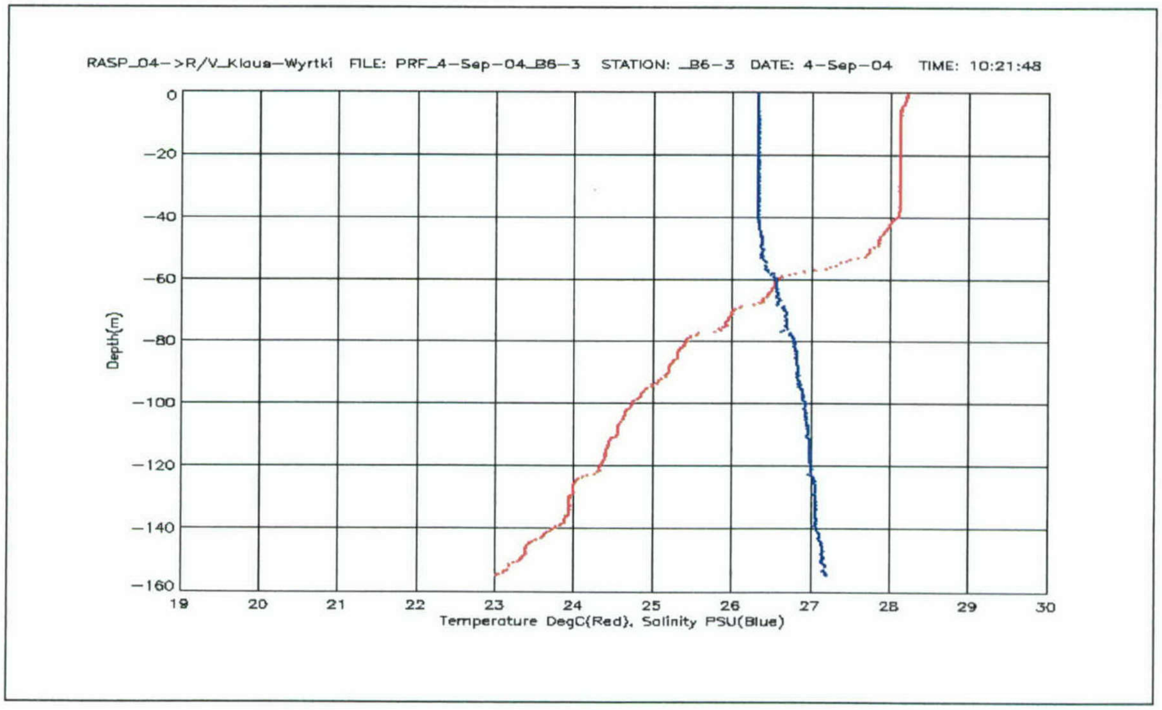

Figure 5. Example of temperature (red) and salinity (blue) vs. depth.

In addition, time-series plots are provided. Data from each station (B6-1 through B6-7), for the entire period of the experiment, were imported into an excel spreadsheets and a time series of absorption at 412nm (a412) for each station was plotted. (example shown in Figure 6). These plots illustrate the temporal variability at a single station over time. Finally, for each day, depth profiles of a412 at all stations were plotted in a single figure, to illustrate the spatial variability across the area on a single day (example shown in Figure 7). Figures for all stations and dates are provided as hardcopies in the attached data binder and in the excel spreadsheets on the data CD.

The excel time-series plots of a412 vs. depth for each of the seven stations show similar variability and data ranges. Absorption in this clear-water environment was extremely low, with a412 values ranging from about 0.02 – 0.13 m^{-1} over all stations, depths, and times. With regard to the optics, a stratified water column was observed at all stations over the entire course of the experiment, although the stratification was somewhat weaker on some days. Typically, low absorption coefficients were observed in the upper 40 m or so of the water column at all stations, with higher absorption values deeper (a412 values were generally about 2X higher in the subsurface layer compared to the surface layer; see excel time series plots in accompanying data binder or on accompanying data CD). A more pronounced subsurface maximum was observed around 50-80 meters toward the end of the experiment (3, 4, and 5 September) at stations B6-1, B6-2, B6-3, and B6-4, whereas the water column stratification was somewhat weaker over this same time period at stations B6-5, B6-6, and B6-7. Occasionally, a bimodal subsurface maximum was observed, as at stations B6-3 and B6-4 on 5 September.

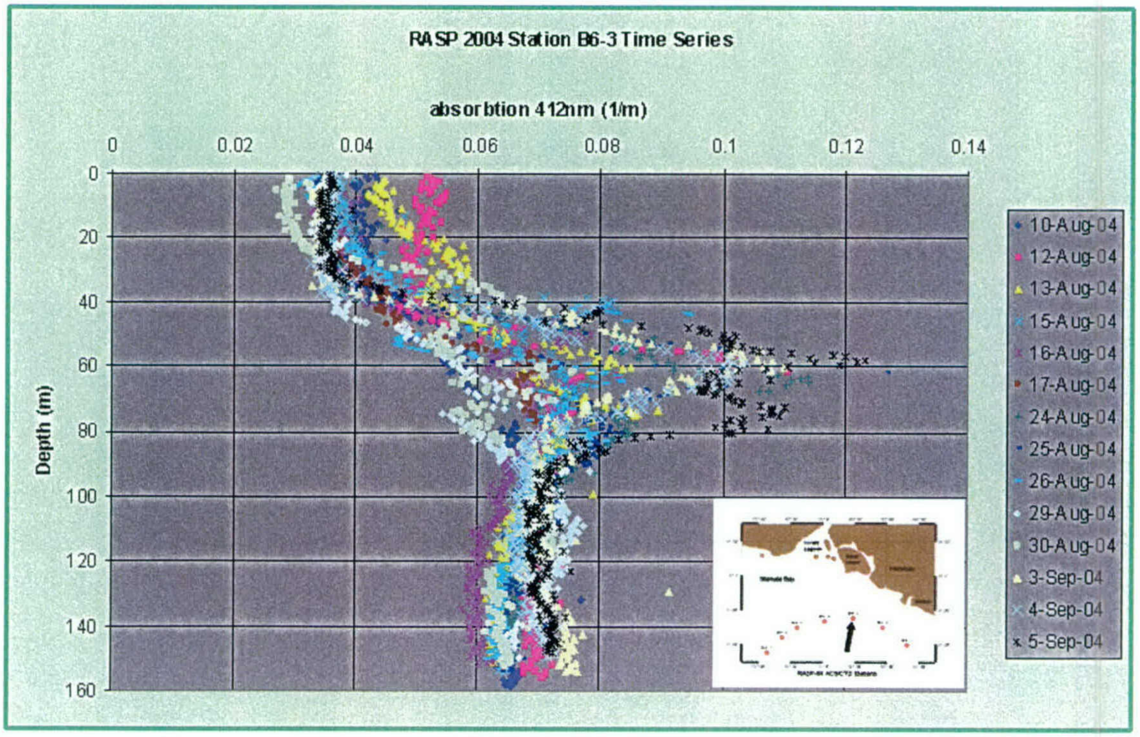

Figure 6. Example of ac9 absorption coefficient at 412 nm (a412) vs. depth, all sample dates at a single station (B6-3).

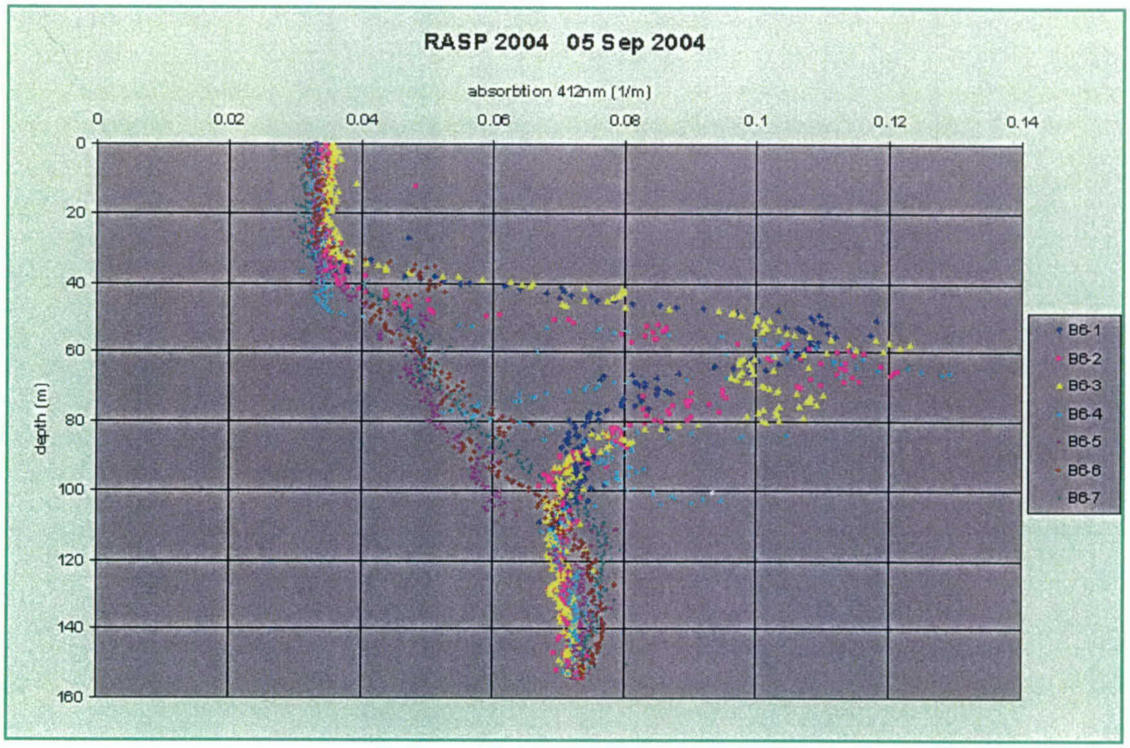

Figure 7. Example of a412 vs. depth, all stations on a single day (5 September).

The optical scattering coefficient (b), was calculated as the difference between the attenuation and absorption coefficients (b = c – a). In general, surface scattering values at shorter wavelengths were slightly larger than or roughly equal in magnitude to the surface absorption values. At depth, the scattering values were very low, and some of the calculated scattering values at the blue wavelengths (412 – 440 nm) were slightly negative near the bottom of some of the ac9 casts, because the measured absorption values (a) exceeded the measured attenuation values (c). These negative b values are clearly erroneous. However, these data were found to be within the measurable limits, or accuracy, of the ac9 meter and hence were not removed from the data files. Note that the corresponding a and c values are not negative, but are very close in magnitude, merely indicating little to no scattering.

NRL/SSC has extensive expertise in the processing and analysis of aircraft and satellite ocean color imagery. To demonstrate our capabilities, and to provide a comparison of measured and satellite-derived optical properties, NRL/SSC downloaded the SeaWiFS satellite imagery from the NASA/Goddard Distributed Active Archive (DAAC) system. We browsed the image archive for cloud-free scenes corresponding to the *in situ* sampling dates and found three scenes (14, 15 August; 4 September). We then processed each of the three cloud-free scenes using NASA and NRL bio-optical algorithms and we extracted absorption values from the imagery at pixel locations corresponding to station locations. The comparison between the ac9-measured absorption values and the satellite-derived values are shown in Figure 8, for 5 of the

wavelengths. There is good agreement between the satellite and *in situ* absorption values. **For future experiments, NRL could process and analyze satellite ocean color imagery to provide greater spatial coverage of optical properties, and provide the imagery and data to NAVAIR in addition to the *in situ* measurements, if desired.**

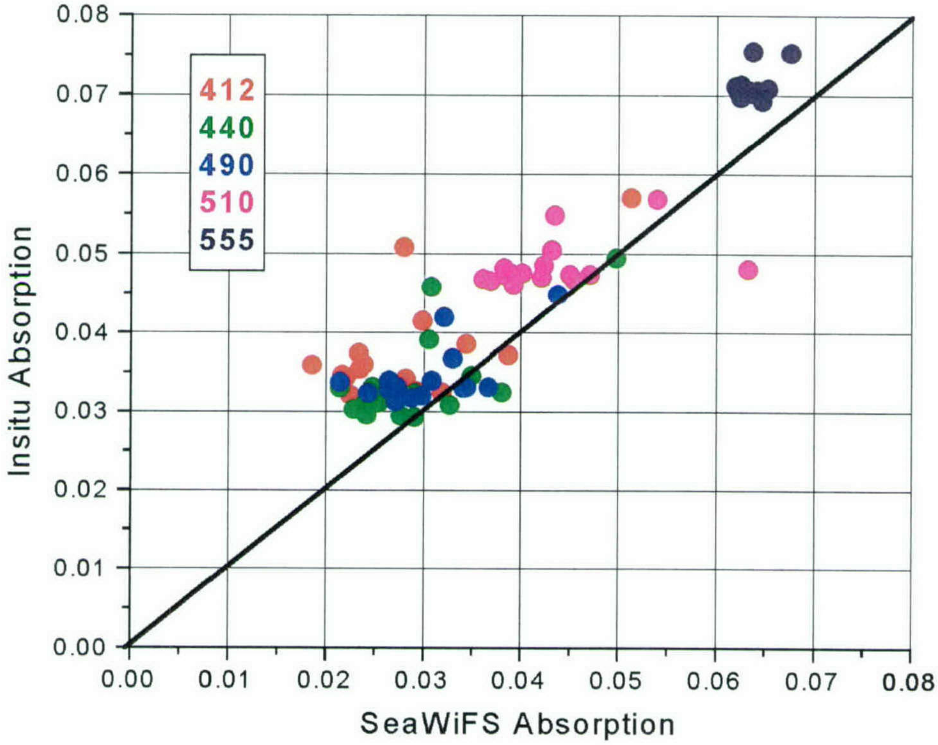

Figure 8. Ac9-measured in situ absorption values vs. SeaWiFS satellite-derived absorption values. Units are m^{-1}. The colors represent wavelength, in nm. Satellite data are extracted at ship station locations from three cloud-free scenes on 14 and 15 August and on 4 September.

Summary

A high-quality optical data set was collected by NRL/SSC during the RASP-04 experiment in Hawaii. Very low absorption and attenuation coefficients were measured over the course of the experiment, and optical variability, both spatially and temporally, was relatively low as well. The upper 40 m of the water column was well-mixed and fairly uniform across the study area (a412 values of approximately 0.04 m^{-1}). A gradual increase in a412 was generally observed between 40 and 80 m, although a distinct subsurface optical layer with elevated absorption and attenuation values was frequently observed around 50-70 m. Below about 80 m, the water column was well-mixed and a412 values were fairly uniform (approximately 0.07 m^{-1}). ASCII data files, excel spreadsheets and plots, and postscript plots are provided on the data CD accompanying this report.